

**APPLICATION FOR UNITED STATES
LETTERS PATENT**

SELF-TIMED READ AND WRITE ASSIST AND RESTORE CIRCUIT

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SELF-TIMED READ AND WRITE**ASSIST AND RESTORE CIRCUIT****BACKGROUND OF THE INVENTION**

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1. Field of the Invention

The present invention relates to random access memory technology and architecture, and more particularly to tolerating large threshold voltage fluctuation in memory cells.

2. Description of the Related Art

Large threshold voltage (V_t) fluctuations due to random placement of dopant atoms in small geometry static random access memory (SRAM) cell metal oxide semiconductor field effect transistors (MOSFETs) significantly degrades SRAM array yields in functionality and performance. Presently, there are no known circuit solutions to address this limitation other than brute force reverse scaling of SRAM cell transistor geometries and cell size. One drawback

of the reverse scaling approach is that it increases the production cost of the device by increasing die size significantly. Thus, making high performance processors more expensive.

5 Therefore, a need exists for a structure and method, which counters the negative effects threshold voltage fluctuation in memory cells.

SUMMARY OF THE INVENTION

10 A read and write assist and restore circuit for a memory device includes a first device, which is responsive to a potential on a bit line such that the potential on the bit line activates the first device. A second device is driven by the first device such that when the first device
15 is activated, a change in the bit line potential is reinforced with positive feedback by the second device during a wordline active period to enable write-back of data lost as a result of threshold voltage fluctuations in memory cell transistors coupled to the bit line.

20 Another read and write assist and restore circuit for a memory device includes sensing device responsive to a

potential on a bit line such that the potential on the bit line activates the sensing device, and a driver device driven by the sensing device such that when the sensing device is activated, a change in the bit line potential is reinforced with positive feedback by the second device during a wordline active period to enable write-back of data lost as a result of threshold voltage fluctuations in memory cell transistors coupled to the bit line. A virtual ground provides a higher potential than a global ground to the memory cell transistors to assist in write operations and during standby.

These and other objects, features and advantages of the present invention will become apparent from the following detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

FIG. 1 is a schematic diagram conceptually showing operation of a memory cell, during a read operation;

FIG. 2 is a schematic diagram showing a read and write assist and restore circuit in accordance with an illustrative embodiment of the present invention;

FIG. 3 is a timing diagram for a simulation of a prior art SRAM cell showing data loss;

FIGS. 4 and 5 are timing diagrams for a simulation of a circuit employing a read and write assist and restore circuit of the present invention; and

FIG. 6 is a schematic diagram showing a virtual ground enabling circuit in accordance with an illustrative embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention captures data being read by a bit line (BL) from a memory cell, before the cell asymmetries due to Vt fluctuations upset the cell. The captured data is restored to the cell while the word line (WL) is still selected, enabling the cell to retain data

that would be otherwise lost.

It should be understood that the present invention will be illustratively described in terms of an SRAM cell; however, the present invention is much broader and can be
5 used with other memory storage devices, such as register files and DRAM or even other storage or capacitive elements that are affected by threshold voltage fluctuations.

Referring now to the drawings in which like numerals represent the same or similar elements and initially to
10 FIG. 1, a half ($\frac{1}{2}$) cell 10 is illustratively shown to demonstrate the operation of the present invention. Cell 10 may be any type memory cell, e.g., SRAM, DRAM or other memory cell. In FIG. 1, cell 10 includes an SRAM cell having a plurality of MOSFETs. Cell 10 is preferably
15 included in an SRAM memory circuit 12 in a memory array region. Although, memory cell 10 may be include as a single device, for example, on an application specific integrated circuit. In an array region, circuit 12 includes a plurality of cells 10.

20 Half cell 10 shows three transistors, however a full

cell may include six transistors. PFETs and NFETs may be switched as would be known to one skilled in the art.

The present invention uses devices having a threshold voltage V_t . A word line (WL) is included in the gate of device 16 and is activated with a supply voltage, V_{dd} , by the word line (WL). When the WL selects a row of cells, each cell begins pulling down (one of 2) precharged BLs with its cell read current I_{read} .

In a conventional SRAM, the cell storage node at '0' rises to a voltage determined by a voltage divider between the precharged BL and the cell ground GND across cell transistors 16 and 18. If the V_t of the cell access transistor, 16 is smaller due to a V_t fluctuation, and/or if the pull-down transistor 18 has a larger V_t due to random V_t variations, then the node at '0' rises high enough to potentially trip an inverter (e.g., device 18 and 20 form an inverter on the half of the cell shown, a mirror image is included on the other half) formed by the transistors (not shown) on the other half of the cell. The positive feedback between the two cell inverters then

ensures that the cell flips state and the data originally stored is lost.

The present invention uses the fact that the cell with severe V_t fluctuation takes a finite time to flip. This time will be referred to as T_{data} . T_{data} is usually long enough for the BL pair driven by the unstable cell to capture the data from the cell that is sinking read current (I_{read}) and developing a differential voltage signal across the BL pair. A more unstable cell is also faster (smaller V_t in access devices degrades cell stability and increases read current). V_t increases in the cell transistor 18 do not affect the node voltage at '0' as much as transistor 16 does. In addition, V_t increases in transistor 18 do not occur as often as V_t decreases do, since the skew in the V_t distribution favors smaller V_t from short channel effects.

Referring to FIG. 2, a self-timed read and write assist and restore circuit 100 is shown in accordance with one illustrative embodiment of the present invention. Circuit 100 may be placed within an array of cells 110 and is coupled to a bit line BL. During operation, transistors

112 and 120 are enabled by a subarray select bar signal and a subarray select signal, respectively. Once activated, a faster cell (unstable cell with a large V_t fluctuation) in subarray 111 sinks BL charge, dropping the BL voltage. At the same time, this charge drop activates a transistor 114. Transistor 114 has a gate connected to BL, which turns on the PFET 114 when the BL voltage drops below its threshold. PFET 114 in turn drives a device (NFET) 118, which, on turning on begins to 'assist' a selected SRAM cell in developing signal on the BL. Transistors 114 and 118 are preferably low threshold voltage device (LVt) or may have their threshold voltages adjusted during fabrication to handle predetermined condition on BL.

Advantageously, feedback action is provided in the assist circuitry 100, which is self-timed in that there is no external signal that is needed to initiate this feedback mechanism. The feedback is initiated by the voltage of the BL itself. The sensitivity of the feedback to the BL voltage is controlled by body bias (BB) on the well of the PFET 114 or the well of the PFET 114 and the NFET 118.

In the embodiment shown, the read assist mechanism is gated by the sub-array select and subarray-select-bar signals also shown below so that the feedback can be invoked only when the subarray is selected. Note also that
5 the feedback does not degrade the write operation. Instead, the feedback 'assists' the write in providing the write buffers with more drive, potentially relaxing their drive strength requirements.

Referring to FIG. 3, a conventional SRAM cell
10 simulation is shown without read assist or the present invention. The circuit simulation demonstrates the read upset due to V_t mismatch in a conventional SRAM cell. According to FIG. 3, data is lost on the left bit line (left BL) as indicated in a region marker 202. A CLK
15 signal shows the read (R) and write (W) cycles. WL shows the word line signal. Left cell and right cell show the data signals for storage in a given half of a cell. T_{data} is the time needed for a cell to flip. In the flip region, static noise margin (SNM) = 0, and the voltage at node '0' (see e.g., FIG. 1) is greater than $V_{critical}$ (V_{crit}).
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Vcrit is the minimum node voltage needed to trip the cell state. As a result of the reduced bit line voltage a false read cycle was experienced as indicated by label 204.

Referring now to FIG. 4, a simulation of an identical
5 SRAM cell with read assist in accordance with the present invention is shown. The simulation of FIG. 4 demonstrates that the cell is able to hold data even in the presence of large Vt variations (e.g., despite Vnode exceeding Vcrit). As shown in FIG. 5, the symmetrical matched SRAM cell
10 simulation with the addition of read assist circuitry shows that performance is maintained using read assist circuitry of the present invention. FIG. 5 shows bit line timing for right and left BL signals.

15 WRITE ASSIST using SRB

Referring again to FIG. 1, the noise margin for a write operation is smaller when Vt of the cell access transistor increases. This is because, the cell node at '0' is being held low by the pull-down NFET 18, which
20 fights the pull-up device 20 of the write driver that is

trying to write a '1' to that node. If the cell access transistor Vt is large enough, then there will be enough of a voltage drop across 16 to inhibit the write driver 20 from raising the voltage of the node at '0' making it
5 harder to write data into the cell.

However, on keeping the cell ground voltage(VGND) higher than ground (GND) during a write operation, the cell pull-down NFET 18 is much weaker because its gate-source voltage is smaller, making it easier for the write driver
10 20 to flip the cell, large Vt variation in the cell access transistors notwithstanding.

The write assist operation may be implemented using a technique disclosed with reference to FIG. 6 by not activating a SRB READ signal for write operations and
15 during standby. This ensures that the VGND stays at Vt above ground during writes and during standby.

Referring to FIG. 6, a schematic diagram provides an illustrative model circuit to explain VGND for write operations in accordance with the present invention.

20 In a logic portion 304 of circuit 300, a virtual

ground line VGND connects to VGND of array 302. VGND is coupled to global ground GND via one or more transistors 334 and 336. Transistor 334 may include an NFET which has its gate controlled by an SRB (self-reverse bias) signal.

5 Transistor 336 may include a PFET which has its gate controlled by an SLP_mode ("sleep" mode) signal.

During idle mode, nodes 322 (and 323) store a one or a zero. In conventional systems, leakage through NFETs 314 and 316 to GND caused charge (ones) from storage nodes 322
10 (and 323) to discharge. By employing VGND at a value greater than GND, leakage is reduced. Transistor 336 acts as a diode in pinning the VGND at a voltage (e.g., V_t above GND). Hence, charge that builds up in VGND during idle mode increases the potential of VGND. When the VGND
15 potential exceeds a threshold value, charge leaks through to GND, through device 336 thereby pinning the voltage, which can build up on VGND. Cell 110 includes transistors 310-320 for operations of the SRAM cell as described above (see e.g., FIG. 1) with the assist circuitry of FIG. 2 in
20 accordance with the present invention. Note BLB is bit

line bar.

Having described preferred embodiments of self-timed read and write assist and restore circuit (which are intended to be illustrative and not limiting), it is noted
5 that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the invention disclosed which are within the scope and spirit of the invention as outlined by
10 the appended claims. Having thus described the invention with the details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.